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HYDROLOGY
and the

UNIVERSAL
SOIL
LOSS
EQUATION:

APPLICATION
TO
RANGELANDS

by

Richard H. Hawkins

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APPLICATION TO RANGELANDS

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Richard H. Hawkins
North Logan, Utah
February 1985

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PREFACE

This report was prepared under Bureau of Land Management Contract No. YA-558-PH-3-1007 as part of an effort by a committee of government and university erosion specialists to address the use of the Universal Soil Loss Equation (USLE) on Western United States rangelands. The USLE is one of the most useful procedures for estimating long-term average annual soil loss caused by sheet and rill erosion. The objective of the committee was to improve the application of USLE on rangelands given the current status of our knowledge. A user-oriented guide for predicting sheet and rill erosion on rangelands using USLE is being prepared as a separate document.

A second objective of the committee was to provide an informed discussion of USLE, emphasizing some of its inherent limitations and offering positive suggestions for future research and development of rangeland erosion prediction procedures. This report contributes to that objective.

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HYDROLOGY AND THE
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Abstract: The interactions between hydrology and erosion associated with the Universal Soil Loss Equation (USLE) are developed and discussed. It is argued that runoff plays an important but underappreciated role, and that certain problems encountered in USLE use can be so attributed. The site and climatic conditions encountered on rangelands exaggerate these difficulties. Some avenues for future research and use are suggested and explored.

INTRODUCTION

The purpose of this essay is to illuminate and discuss the role of hydrology in the Universal Soil Loss Equation (USLE), and thus to suggest some avenues of possible research and development for its more credible use. The discussion concerns less process detail than associated with currently emerging erosion models, but is more process oriented than USLE's traditional empirical application. Furthermore, while the approach is general, it will accent USLE use and applicability on western rangelands.

The equation, $A=RKLS\overline{C}P$, will be accepted as understood by current usage, and its background and customary application will be described only as necessary to establish rhetoric. It is covered in great detail elsewhere (8).

A basic assumption throughout is that USLE land erosion, in event or long-term average terms, does indeed require overland flow. The process of detachment, transport and deposition require water movement, without which there would thus be no land erosion phenomenon to contemplate (with the exception of the splash component).

Thus the equation does not lead directly to erosion, but produces the intermediate product of storm runoff. Prospects for resolution of the complex interactions between USLE and runoff are not immediately encouraging. Despite its importance and long study, the state-of-the-art in storm runoff is fairly approximate and empirical. The complications of time and spatial variations in site properties are usually not considered, even when of known importance. They will not be treated here: areal homogeneity will be assumed for the land surfaces.

BACKGROUND

Technical Considerations

1. Erosion: The output of the equation, A , is understood to be an average annual long-term value (usually in tons/ac-yr), resulting from a rainfall system, and not including downstream channel erosion. It includes on site rill and interrill erosion in a net sense. That is, while local on-land deposition may occur, it is not considered. The elemental unit area is taken as 0.01 acre, corresponding to the original data plots of 6 x 72.6 ft. The item of importance here is the matter of the long-term average. This erosion may also be expressed as the sum of a number of discrete events or

$$A = \Sigma A_e / N_y \quad [1]$$

where A_e is the erosion from a specific event, and N_y is the number of years encountered. This relationship will be exploited subsequently.

2. Rainfall Energy: The R factor is calculated from the sum of storm R values over a long period of years. The calculation dwells on the energy of impacting raindrops, and the equations for doing so embody assumptions on the drop diameters and their distribution, the velocity of the drops, leading to an empirical equation giving interval energy solely as a function of burst intensity;

$$e = 916 + 331 \log_{10} i$$

[2]

where e is in Ft-tons/Ac-in, and i is in inches per hour.

Such considerations (i.e., energy, velocity, etc.) are intuitively cogent for situations of bare-tilled turned soils commonly encountered in traditional agricultural settings. However, consider a condition of heavy cover, such as a pasture, forest litter, or stones. Raindrops, and their energy, are then intercepted, momentarily stored, and then fall to the surface, effecting some delivery smoothing but greatly reduced fall heights. In such a case, the energy expression of R becomes meaningless and the R factor probably performs in a purer hydrologic role. The cover factor is used to functionally carry out this modification. It is sufficient that the calculation of R for storms includes both intensity and storm depth regardless of its energy portrayal. Thus R may well perform (in at least some cases) more as a stand-in for the driving hydrologic variable than a true energy erosion factor.

The formal calculation of R excludes all events of less than 0.5 inch depth, a practice based on experiences which found better correlation with A . This is equivalent to declaring that events with $P < 0.5$ inch fail to induce significant erosion or runoff. In terms of applied hydrology, this infers an initial abstraction (rainfall necessary to initiate runoff) of 0.5 inches. Curiously, for the CN method, this specifies $S=2.5$ inches, or $CN=80$, an acceptable value for many agricultural lands from which USLE was originally derived.* The notion of initial abstraction depth, and its accompanying energy will be further developed later.

Finally, the storm event R may be considered a random variable, and thus expressed and treated in terms of probability distribution. No

*Hudson (3) suggests an intensity threshold of 1.00 in/hr for tropical situations. Drawing from published values of saturated hydraulic conductivity and its application to the Green-Ampt equation (2), this indicates sandy or loamy sand soil textures.

display examples of this are known, though preparation would be a routine technical task from long term storm data. In subsequent discussion, event R will be termed " r_e ".

3. Soil Erodibility: The soil factor "K" is usually considered as intrinsically unique, depending on texture, structure, organic material content, and to a small degree permeability. However, numerical determination of "K" from field data is carried out by analysis of observed relationships between the erosion "A" and the parameter input product RLSCP. The slope $A/RLSCP$ represents K. The erosion A (the sum of event erosions A_e) hangs on the event runoffs, and is thus responsive to variations and assumptions in R (such as $P > 0.5$ inch), and the antecedent conditions known to be important in event runoff. Thus, K, as locally calibrated is not a specific soil constant, but also a reflection of hydrology.

This difference in performance may be further rationalized by considering two otherwise identical soil plots, one in a semi-arid western situation (say, Boise) and one in a humid midwestern situation (say, Indianapolis). Because of natural differences in rainfall characteristics, the Indiana plot will experience greater antecedent moisture, more frequent runoff events, and more intense bursts within storms. The soil behaviors on the two plots can hardly be expected to be identical.

4. The Role of Soil Texture: The connection between the runoff and erosion results in an interesting interplay when viewed through the window of soil texture. Arraying texture on a spectrum of "fine" to "coarse"--an admitted oversimplification--the runoff and erosion characteristics can be generalized.

Infiltration capacity varies directly with soil texture. That is, the larger the soil particles, the faster the rate of water intake. The rainfall excess rate then, varies inversely with soil texture: the larger the soil particles, the lower the rate of rainfall excess. Thus runoff from coarse textured soils is relatively rare, from fine textured soils relatively common.

Soil erodibility, however, varies inversely with soil texture.* Coarse-textured soils are loose and poorly attached, thus inclined to erode when overland flow is present. Extremely fine textured soils (clays) often manifest pronounced bonding at the particle level, providing a bulk resistance to erosion when overland flow exists.

Erosion, however, is the joint function of both flow and soil erodibility. In a conceptual sense at least, $Erosion = Flow \times Erodibility$. Thus when either flow or erodibility is absent, there is no erosion. The maximum erosion must occur at some intermediate stage. These relationships are shown in graphical-conceptual form in Figure 1, with maximum erosion

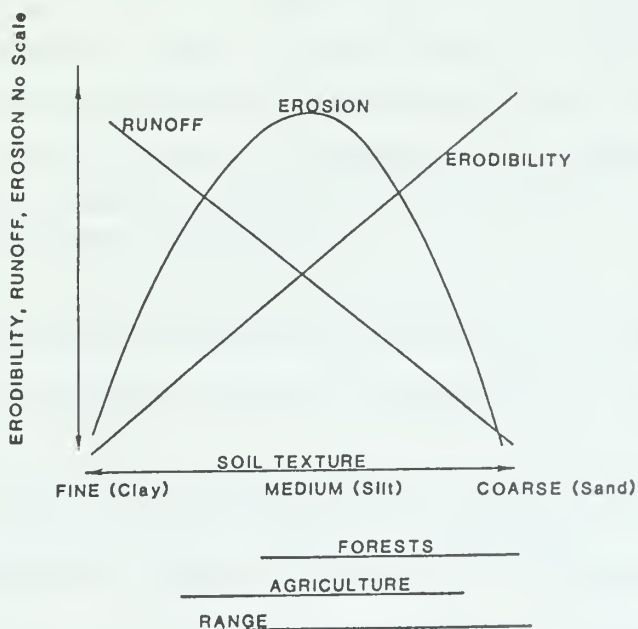


Figure 1. A simplified conceptual representation of runoff, erodibility, and erosion as a function of soil texture. The range of texture normally associated with various land uses is also shown.

*See, for example, Bouyoucos (1), who proposed an index of erodibility based on soil texture as $(\% \text{ silt} + \% \text{ sand})/\% \text{ clay}$.

shown at a medium texture. While the rhetoric here is approximate and further limited by rainfall assumptions, the conclusion is supported by overall field observations. Agricultural land dwells more on moderate or fine textured soils, and in rainfed situations has higher intensity and more frequent events. Thus, USLE is drawn from a data base centered on the more erosion-prone situation.

Rangeland: Because the concern here is erosion on "rangelands", it is worthwhile to discuss the distinction between "rangelands" and agricultural lands, and their different properties. The USLE was originally intended for and developed from data in agricultural settings, and any differences in the two conditions are potentially important.

As customarily used, the word "rangeland" refers to grazed (or potentially grazeable) wildlands. There are, of course, indistinct borderline cases, such as abandoned dry croplands, intermittently grazed woodlands, humid pastures and meadows, and extremely arid wastelands. However, for purposes of conceptualization here, the traditional conditions found in the semi-arid western U.S. public domain may be used as a reference example. Similarly, agricultural endeavors cover a wide spectrum, though common attributes tend to surface. The mixed farming found in the midwestern and eastern US may be used here as a conceptual point of departure, and the agronomic facets of agriculture assumed.

The primary distinction between rangelands and agricultural lands is economic. Lands of sufficient quality to endure profitable intensive use tend to be so dedicated. Lands are in range use largely by default. Agronomic agriculture is usually a higher and more profitable land use. The default logic and profit motivation springs from a series of natural land attributes, and causes several consequent derived conditions. The following paragraphs describe and contrast these settings for idealized range and agricultural lands. Though overlaps, exceptions, and unusual settings do exist, some valuable generalizations may be drawn.

1. General Conditions: Rangeland management historically has been performed with minimal capital, labor, and energy utilizing natural

inputs and the natural environment, with some attention to the grazing animal. Harvest may be periodic or aperiodic of a diffuse resource covering large land areas. Unit area production is low. Agricultural management is high intensity, incorporating the natural environment and more user-supplied inputs of energy, chemicals, and technology. Harvest is more direct, frequent, and concentrated, and on smaller land areas. Unit area production is high.

2. Geographic Setting:

Topography: Agricultural lands are generally more level, accessible, continuous, and interconnected. Rangelands may be dispersed, inaccessible, steep, and rugged.

Climate: Agricultural lands have more favorable moisture conditions and growing seasons. Indeed, moisture may be supplied from external sources to otherwise arid lands for agricultural purposes. Rangelands may be dry, cold, hot, and/or of short growing season. The moisture-heat criteria is perhaps the most distinctive difference between agricultural and range endeavors.

Soils: Agricultural soils are usually deep, well developed, non-stony, fertile, medium textured, and non-saline. Range soils may be shallow, poorly developed, stony, infertile, saline, and of a variety of textures. Soils may even be essentially non-existent in some rangeland situations. Agricultural soils require favorable soil moisture conditions, which are not always found on rangelands.

Rangelands usually have naturally-developed soil profiles, with consequent hydrologic properties. Agricultural soil management practices result in soil homogenization, particle breakdown, plowpans, and loss of structure and organic material. Agriculture is usually a soil-disturbing process. In both conditions, substantial areas of bare soil may be present, though more vulnerable to erosion in freshly-exposed agricultural settings.

Vegetation: Agricultural vegetation is highly specified and managed, and the species composition may vary markedly from year-to-year. Range vegetation may include native cover well adapted to local sites, as well as non-beneficial woody plants or toxic vegetation. Cover does not usually vary substantially from year-to-year.

Hydrology: Rainstorm response is more common on agricultural lands than on rangelands. This may be seen as the expected consequence of finer soils, heavy use, higher soil moisture, and the more frequent rainstorms of higher intensity and greater depth. There are severe differences in rainfall depth frequency-intensity (and storm rainfall energy) between the agricultural midwestern US and the large bulk of rangelands in the western US. Accepted notions and pursued concepts of rainstorm response were formed from experience in humid agricultural situations.

3. Technical and Professional Conditions:

Because rangelands are low valued, remote, and sparsely inhabited, local environmental data on them is usually scarce. There is little serendipitous climatic data from nearby towns, and only scant research on rangeland hydrology. On the other hand, civilization clusters around agriculture, and society's concern for the continued agricultural productivity is widespread. Several well-developed professions (Agricultural Engineering and Agronomy, for example) service agriculture's needs, and hydrologic techniques are available specifically for agricultural lands. No such situation is yet present for the rangeland case.

The above rhetoric, while idealized, suggests some distinct differences between "rangelands" and the agricultural situations from which USLE was developed. Transfer of the technology should be done with a conscious awareness of these differences.

Methodology Comparison: Because of the wide and largely uncritical use of USLE, and because of the prominent role it plays in applied hydrology, it

is worthwhile to examine, its "social" setting and pedigree in the spectrum of hydrologic methodologies. It is especially rewarding to compare it with its sister technology, the widely used rainfall-runoff model called the "Curve Number" method. The similarities, differences, and analogies offer sobering perspective and insight, and make comparisons worthwhile.

1. Origin: Both techniques arose from the U.S. Department of Agriculture, and at about the same time, i.e., in the post-war period of agricultural technology development and water awareness. As a common date, the 1950-60 decade might be used to identify the ascendancy of both methods.

2. Intent: In both cases, the intent was agricultural conservation planning in the absence of more precise information on ungaged areas. The goal was administrative and engineering design decision making, within acknowledged broad boundaries.

3. Derivation: In both cases, the information base used was almost entirely agricultural and/or humid and subhumid situations. This was natural, considering the availability of data and the mission accent of the originating agencies. Many generally accepted hydrologic concepts were founded largely on experiences with humid agricultural lands.

4. Application: Though not always clearly stated, the use was prescribed within statistical limitations. The USLE was to deal with long term average annual erosion (not specific events, specific years, or sediment delivery or sediment yield), and the CN method was merely a transformation of frequency maximum daily rainfall depths (annual series) to a corresponding series of frequency runoff depths (not specific storms or activity within a storm).

5. Subsequent use: Because of the need for more specific or detailed calculations, the limits of use and geographical application were exceeded almost immediately. The CN equation became applied as an infiltration (loss rate) function and applied to design storms. Both methods have been applied to geographical situations well beyond the original data base.

Following original development, each method has undergone some modifications for specific application. Those modifications are essentially "add-ons" and do not change the basic structure of the methodologies.

6. Authority and Documentation: On this matter, the two methods diverge somewhat. USLE arose through a well-documented evolutionary process in a research environment (ARS). There is a substantial literature on USLE matters, in both agency publications and technically reviewed journals. The CN method arose abruptly from an operating agency (SCS) without any lead-in documentation, journal presentations, public technical comment, etc. As a result, USLE enjoys better technical acceptance, scientific belief, and wider unchallenged use, even though the objective basis for such faith may be questioned.

7. Defensive Postures: Issue new technical policy, clarify previously unappreciated distinctions, and suggest proper use in new situations. Both methods have been delimited and defended with similar arguments:

1) Default Applicability (" it's the only tool we have"); 2) Practical Suitability ("it works!"), even in the absence of verification data; 3) Limited Use (" it's only an index"); and Situational Misuse ("... it's being used beyond original intent").

8. Interrelationships: Despite independent development and evolution, they are parallel technologies and contain common technical elements. These are briefly mentioned here, and shall be dealt with in greater detail subsequently.

A. Input Information: Both methods use rainfall (or rainfall derived) information as driving variables, and site environmental information as response parameters. It is interesting to appraise each of the site factors in USLE in runoff (or curve number) terms:

K--a soil factor. Soil factors are also used in the CN method to describe CN through the Hydrologic Soil Groupings.

LS--Length and slope: not used in CN method, but generally acknowledged to be influential in generating storm flow and its timing characteristics. Both length and slope are included in several formulations for time of concentration.

CP-- Site vegetative status and land condition factors used in USCE. Handbook CN selection is done from soils, vegetative type, and land condition estimate.

Thus, all the factors groups used in determining CN are present in the USLE. However, no formal cross-descriptions are known, which construct CN from KLSCP or vice versa.

Similarly, the rainfall input to the CN equation is usually on a specified return period, duration, and distribution. Given these elements a storm "R" value (for USLE) also exists. A further association between the two methods is the estimation of the annual USLE "R" from duration-return period rainfall estimates.

B. Role of Overland Flow: Overland flow is implicitly assumed to occur in USLE, insofar as rill erosion is included and hydraulic transport of eroded particles is necessary both in the interrill areas and in the rill channels. Similarly, overland flow is the soul of storm runoff in agricultural and rangelands. Thus both methods deal with it, even though there is no directly stated hydrology factor in USLE. The factors used, KLSCP, must somehow perform in a hydrologic fashion.

Modifications: An innovative extension of USLE is the Modified Universal Soil Loss Equation, or MUSLE (6). In it, the R term is replaced by a runoff volume-peak runoff rate term, leading to

$$A_e = b(Qq_p)^n \text{KLSCP} \quad [3a]$$

This formulation does two things: 1) extends USLE to watersheds, and not simply overland flow land surfaces, and 2) establishes an event basis for USLE.

The modification term $b(Qq_p)^n$, called the runoff energy factor, serves at least as a sediment delivery ratio. However, by virtue of its role and structure, it also serves as a limiting hydrology factor, denying erosion without runoff. Because it is applied on a watershed basis, it must also carry an accounting for runoff from all sources, and not just overland flow. Other sources of runoff (and thus erosion) would include quickflow and channel activity.

Suggested values of b and n for metric calculation are 11.8 and 0.56 respectively, when Q is in m^3 and q_p is in m^3/sec . A test of the method using co-simulated values of Q and q_p (i.e., values simulated and not observed) found high r^2 between modeled and observed sediment masses (7). However, it overpredicted for small storms and under-predicted for large storms, which could well result from errors in modeling the Q and q_p needed for the runoff energy term. Subsequent fitting of the b and n coefficients on real data from several watersheds in southern Idaho found a distinct lack of consistency (4).

A more general extension of the runoff energy-rainfall energy expression has been proposed by Onstad and Foster (5) as

$$A = (aR + (1-a)bQq_p^n) \text{KLSCP} \quad [3b]$$

where the coefficient "a" serves to allocate the energy source between rainfall and runoff fractions. For $a=0$, MUSLE results, and for $a=1$, USLE results. The factor "a", which must fall between 0 and 1, might be estimated from knowledge of the local hydrology.

Both seem to be defensible approaches to marrying erosion and hydrology at the event level. Further development, testing, coefficient

definition, and refinement should be pursued. An analogous approach will be presented in general terms subsequently.

PROBLEMS AND OPPORTUNITIES

Problems: The need to service a wider array of environmental problems in recent years has led to increased use of USLE in situations which stressed its validity. This has promoted a deeper appreciation of its limitations, occasioned more inquiry into its functioning, and pricked professional consciences on its appropriate application in non-agricultural roles. With this comes the awareness of problems associated with the hydrology known to accompany erosion. These problems include 1) Difficulties with rare runoff landscapes 2) Calibration of USLE parameters on discrete events, and 3) Inclusion of snowmelt effects.

1. Rare runoff landscapes: As previously described, many western rangelands are characterized by low rainfall, and thus infrequent runoff. This occurs not only because of the infrequent storm events, but also because of low storm depths and low intensities. Thus soils which might provide several flow events per year in a midwestern agricultural setting only produce overland flow once every several years in a rangeland situation. Furthermore, in more extreme situations, semi-arid landscapes with no history of overland flow over decades of observation can be recognized, provoking the realization that there was no accompanying erosion. However, USLE calculation for such sites yields non-zero estimates of erosion. This paradox is compounded by the geomorphic reasoning and the field observation that such landscapes have been formed by erosional processes, presumably, still "active" in geologic time scales. The USLE appears to fail in such situations. Alternately, it might be held as valid only over extremely long time horizons.

A less extreme variant of this is the mere problem of erosion over-prediction for wildlands via the USLE. This is a commonly held experience among workers in the field, giving rise to the informal underground rule-of-thumb to use ". . . about a third of the calculated value". This problem

is at least in part the result of insufficient coefficients for rangelands situations

2. Event Calibration: Because of the rare event problem described above, attempts to determine USLE parameters by customary on-site plot measurements (so successful in agricultural situations) are often expensive and frustrating. The long term commitment and chancy nature of awaiting natural response has led to rainfall simulation trials as a short-cut. There are however, conceptual difficulties in such a practice. The event imposed is of a selected intensity, duration, distribution, depth, (and thus "R"), and antecedent site conditions. While enlightened choice of these factors and seasonal replications should enhance the portrayal, such trials are still discrete events, while USLE was originally defined in terms of long-term average annual erosion. This average annual erosion is the sum of numerous events of naturally varying characteristics. Furthermore, the calibration is on an equation without a threshold; that is, it is driven through the origin of a rainfall energy (X) vs. erosion (Y) plot. The validity of such synthetic event calibration may thus be justly questioned.

An additional problem should also be mentioned in passing. There is increasing awareness that the spatial variability of infiltration properties within a plot area may cause unpredictably non-linear runoff responses to rainfall intensity. Thus, the intensity selected for simulation runs may bias the hydrology (and thus the erosion) in a very basic sense. Plot area response is calculated assuming uniform areal contributions. However, because perception and treatment of the problem is not yet routine, it is not pursued further here.

3. Snowmelt: While not dealt with in great detail here, some commentary falls naturally in place. As described in above sections, rainstorm runoff and erosion are rare in some western sites, such as forested watersheds, even with substantial overall precipitation input. By the logic of default sources, and from field observation, erosion is seen as arising mainly from snowmelt. This occurs both on land slopes and from erosion of downstream channel networks. The channel erosion is distinctly

outside the intentions of USLE, even from rainstorms. The land erosion source is similar to USLE intent, but the input makes a rational connection difficult. Overland flow from snowmelt, and not the energy per se must be then the driving force. Reasoned use of USLE for snowmelt sources should then proceed from the snowmelt intensity and subsequent overland runoff. Unfortunately, as with rainstorms, snow melting intensity and runoff processes are poorly understood. Progress in snowmelt land erosion prediction will hinge on a better understanding of the associated hydrology.

Opportunities

1. Coefficient Identity: Because of the intertwining of the erosion and runoff processes, it is natural that their prediction should involve overlapping or common factors, and the factor groups be mutually inclusive. As mentioned previously, USLE and the CN methods verify this (except for LS, which undoubtedly influences de facto runoff, but is not directly included in CN calculations), and provide some opportunity for more formal association. Furthermore, specific items excluded in one method should suggest fruitful additions to the other; for example some of the soils factors in USLE not included in the CN method. In its simplest expression, information sufficient to select CN should lead to at least an approximate value of KLSCP, and vice versa.

Additionally, the error notion associated with the Antecedent Moisture Condition concept in the CN method might be extended to the USLE. An analogous statement and procedure might be included in USLE instructions, relating to individual events and annual erosion. Again, because of the necessary connection between runoff and erosion, the CN AMC error bands might be used as a point of departure for such innovations.

2. Landscape Analysis: The shortcomings in USLE raised here should not overlook its usefulness in explaining natural phenomena. Its application as a rough conceptual outline of observed field conditions might be exploited more fully. Perceptive interpretation of its intended

performance could perhaps be applied as a general framework for rationalizing observed surface landscape structure and landforms.

For example, USLE suggests extraordinarily high and frequent erosion on long steep slopes on coarse soils, and high rainfall. Yet apparently permanent uneroded situations exist on many wildland settings of this description. This suggests that despite USLE expectations, no erosion occurs (or else the slope would be eroded away over geologic times), and thus that almost no overland runoff happens. This conclusion matches currently popular contentions in forest hydrology, but which were derived from other lines of reason and observation. In a similar vein, observed uneroded long gentle slopes in semi-arid environments (like western rangelands) might be interpreted in terms of the input rainfall characteristics, and related to explanations of the historical development of the landform.

In more conventional applications, the site characterization KLSCP might be routinely used as a purely descriptive item in land and watershed descriptions in land use planning and watershed analysis.

All of the above opportunities suggest that subjective faith in the use of USLE might be extended to a wider array of applications. To the extent that USLE represents reality it might be imaginatively directed to related subject matters.

ANALYSIS

Runoff and Energy Thresholds: Some perspective and a basis for illustrative discussion can be gained by considering an alternative hydrology-based erosion rationale. That is, event erosion can be recast in terms of threshold hydrology. Their sums (long term erosion) can be equated to the traditional USLE erosion definition, and the input rainfall energy viewed in probabilistic terms.

The threshold runoff depth P_a can be conceived in terms of current technologies: either as I_a in the CN method, or the ponding depth F_p used in Green-Ampt infiltration analysis. Generally considered here, it will be

denoted P_a . Analysis of specific rainfall and site conditions then easily leads to an event R factor to accompany any P_a . This will be denoted r_a , the threshold energy factor necessary to initiate runoff and erosion. Both phenomena begin simultaneously.

The r_a - P_a connection is illustrated in Figure 2. which displays event r_a values calculated for a uniform storm of 1.00 in/hr intensity, utilizing both the Curve Number and Green-Ampt approaches. Soil factors used in the Green-Ampt analysis are taken from a recent paper by Brakensiek and Rawls (2). Naturally, other rainfall distributions and depths will yield different arrays of r_a for the cases considered.

The traditionally-used threshold of $P=0.5$ inch also contains a companion energy factor, which will be denoted $r_{0.5}$. This is the energy factor for a storm of 0.5 inch, and like r_a , which depends on storm distribution and (in the Green-Ampt case) on site conditions. For the CN method, it would be meaningful only at $CN=80$. Values of $r_{0.5}$ for various soils and sites are not shown in Figure 2.

Event Erosion: Given the notion of companion rainfall energy and rainfall depth, and their joint threshold for erosion and runoff, a simple event erosion "model" can be constructed within the confines of USLE. First, the driving variable is not event R (called r_e here), but rather r_e diminished by the threshold r_a , or $r_e - r_a$. The functional form of its action is not known, but, drawing from analogies with rainstorm runoff, can be reasonably supposed as non-linear and concave upwards. In general functional notation it will be denoted $h()$ here. The remaining product term KLSCP will be assumed linear, in keeping with current traditional USLE practice. Thus

$$A_e = h(r_e - r_a)KLSCP \quad r_e > r_a \quad [4]$$

In keeping with the level of the assumptions, no further variable action is postulated. KLSCP will be considered a constant site factor. While the real process is undoubtedly more complex, inclusion of more detail will only add more complications without foreseeable redeeming

UNIFORM STORM $i = 1.00$ in/hr

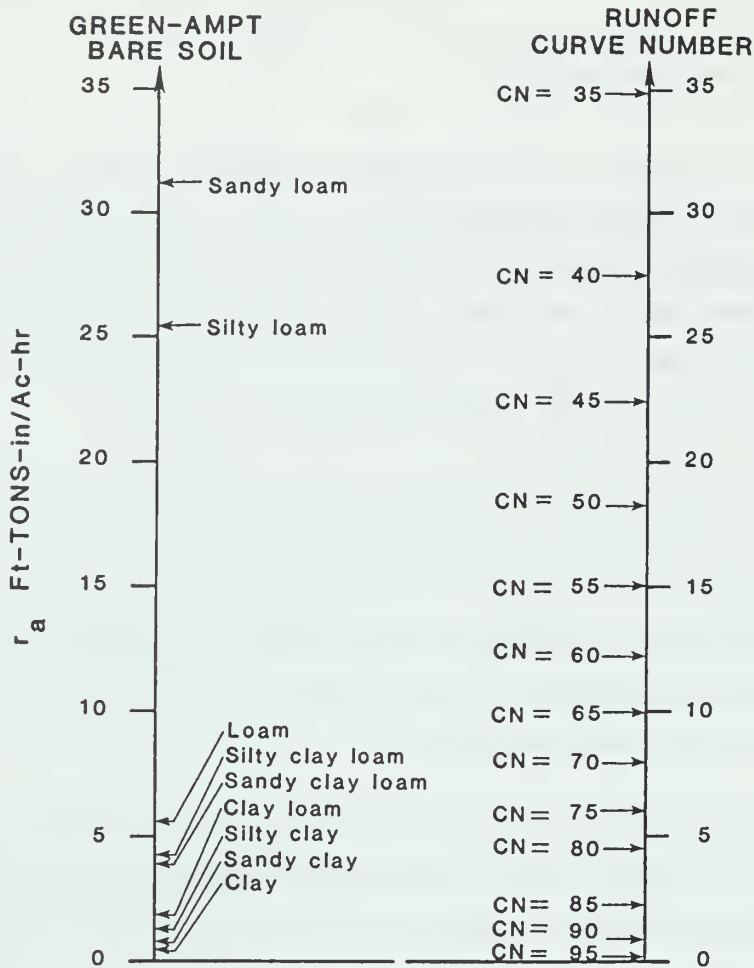


Figure 2. Threshold energy factors for a variety of soil and land conditions, and a uniform intensity storm example of 1.00 in/hr. Soil texture cases were calculated with the aid of the Green-Ampt equation. The factor " r_a " is that necessary to initiate runoff and erosion for the condition shown. The sand and loamy sand textures have k_s 1.00 in/hr, and thus give neither runoff nor erosion for a rainfall intensity of 1.00 in/hr. The values of r_a have already been divided by 100. (The dimensions might more properly be in hundreds of ft-tons-in/ac-hr).

insights. The similarity to MUSLE might be noted, with $h(r_e - r_a)$ replacing the flow-volume flow peak exponent term and coefficient, and serving as the driving variable. The event equation is shown graphically in Figure 3.

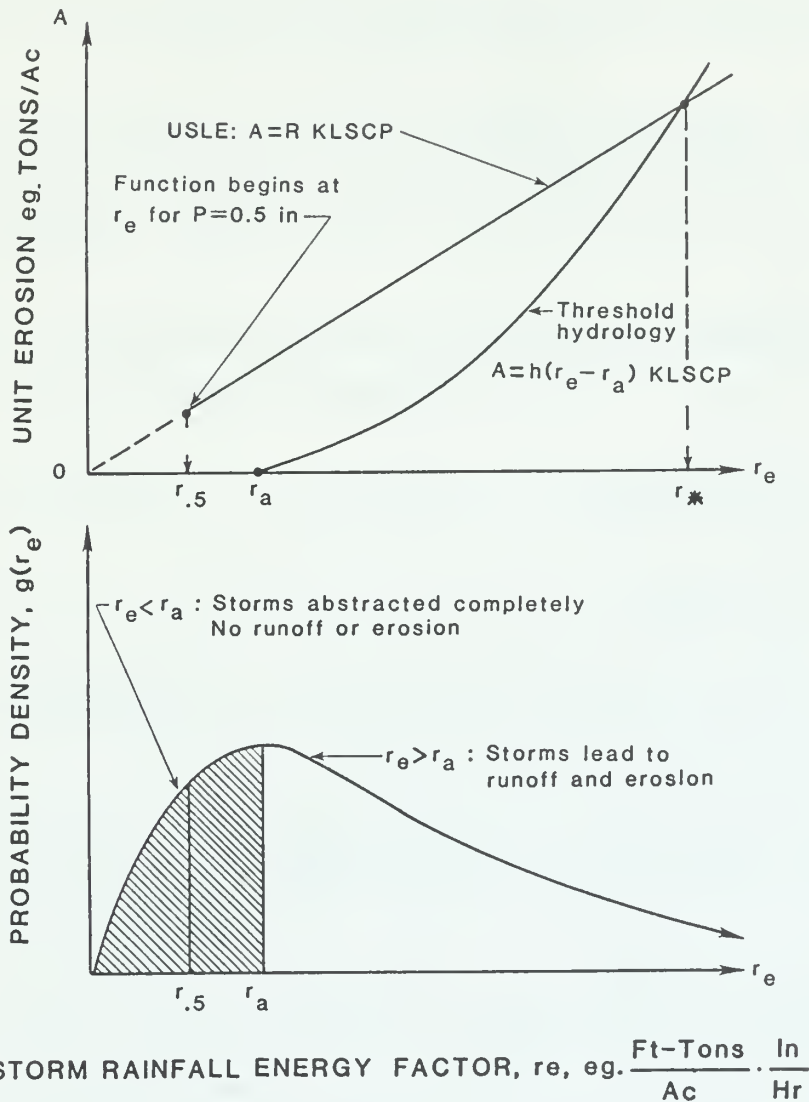


Figure 3a (above) and 3b (below)

- a. Erosion response for USLE and a threshold hydrology representation.
- b. Probability distribution of storm event energy factor, showing $r_{0.5}$ and r_a , and the fraction of storms inducing erosion and runoff.

The r_e axis is the same scale for both figures, which are illustrative only. The relative position and scale shown for $r_{0.5}$, r_a , and r_* are not necessarily in realistic perspective.

As previously described, event energy can be considered a random variable, and its occurrence described by a probability density function. This distribution will be called $g(r_e)$. Though its form is not known, and no displays of it are known in the literature, it is shown with a lower boundary of $r_e=0$ and an expected positive skew in Figure 3.

Synthesis. Pursuing the initial abstraction notion, the difference r_e-r_a might be called the effective storm r_e , and will be called r'_e . Thus Figure 3 is effective only for $r_e>r_a$, and the functions recast as

$$A = h(r'_e)KLSCP \quad [5]$$

$$\text{and } g(r'_e) = g(r_e)/J_a \quad [6]$$

where J_a is the integral

$$J_a = \int_{r_a}^{\infty} g(r_e)dr_e \quad [7]$$

J_a is necessary to assure a unit area for the probability density function.

Now, given $g(r'_e)$ and $A(r'_e)$, i.e. equations [5] and [6], the distribution of A_e can be determined by transforming variables. The details are not given here; the derivation for the general conditions is long and messy, though simple examples can be found in most standard texts on mathematical statistics. The probability distribution of A_e will simply be denoted $m(A_e)$, and assumed continuous for all values of $A_e>0$. It embodies $h(r_e-r_a)$, $g(r_e)$, and the limits of integration for the transforms.

However, given $m(A_e)$, its expected value can be determined through integration, or

$$E(A_e) = \int_0^{\infty} A_e \cdot m(A_e) dA_e \quad [8]$$

The average number of events per year under this condition is

$$N_a = J_a \cdot N_e \quad [9]$$

where N_e is the average number of all storm events of $r_a > 0$ or storm rainfall $P_e > 0$, and J_a is as previously defined.

Now, the average annual erosion is the product of $E(A_e)$ and N_a , or

$$A = N_a E(A_e) \quad [10]$$

This is equivalent to the output intended from traditional application of USLE, so that they may be equated, or

$$RKLSCP = N_a E(A_e) \quad [11]$$

so that simply

$$R = N_a E(A_e) / KLSCP \quad [12]$$

It is likely that in the variable transformation and determination of $E(A_e)$, the product $KLSCP$ would serve as a factor, and be isolated and subject to algebraic cancellation in equation [12]. This is only mentioned here and not carried out.

Equation [12] then reconciles event-by-event erosion summation with the traditional expression of USLE. Potential application might be:

1. Given the site factors and response function ($h(r'_e)$), and the climatic factors ($g(r)$ and N_e), more fitting local estimates of R might be made. These might serve as replacements for or adjustments on existing calculated values of annual R .
2. Given observed A , and the climatic factors ($g(r)$ and N_e) some insights to r_a and $h(r_e - r_a)$ might be gained through data analysis.

Problem Perspectives. The rare event and event calibration problems can now be discussed in the light of the preceding analysis.

First, the rare event problem is embedded in the relationship between $g(r_e)$ and r_a . Figure 3b shows a generous portion of $g(r_e)$ greater than r_a . This image is created by the choice of scale to provide a clear illustration. Field evidence and analysis for specific environments might well show most of $g(r_e)$ below r_a . That is, if $r_a \gg E(r_e)$ then overland flow and erosion events will be infrequent. The existence of no-flow slopes suggests that this may be the case in many wildland scenes. The duration necessary to determine USLE parameters on plots with natural rainfalls is thus seen as a matter of sampling statistics, but hanging on both site conditions and rainfall characteristics.

Further perspective might be gained in this matter through Figure 4, which is a hypothetical portrayal of the performance of a USLE plot in a semi-arid rare runoff environment. The functional structure of USLE presumes a linear (consistent and smooth) relationship between cumulative erosion (on the Y-axis) and the cumulative sum of $r_{0.5}$ KLSCP (on the X axis). However, events happen sporadically, not all create runoff, and when runoff does occur it's neither linear nor purely deterministic. Events of zero runoff and erosion lead to progress on the X-axis with none on the Y-axis, generating the step-like appearance of the plot. Determination of average annual erosion (or any calibration parameters) at any random time, or from individual events, could vary widely, depending upon the fortunes of the sampling scheme. If directly after event #2 in Figure 4 (called e_2), high values would result. If just before e_2 or e_4 , low values would result. A large sample of events over an unspeakable period of years might be required to detect stable estimates. Given the fickle nature of rainfall on western rangelands, the time scale could well be in decades.

The experience of overprediction on wildlands may be explained by the divergence of $r_{0.5}$ (built into USLE) and the reality of a site-dictated r_a . That is, erosion begins when $r_e = r_a$, but USLE calculation is built on

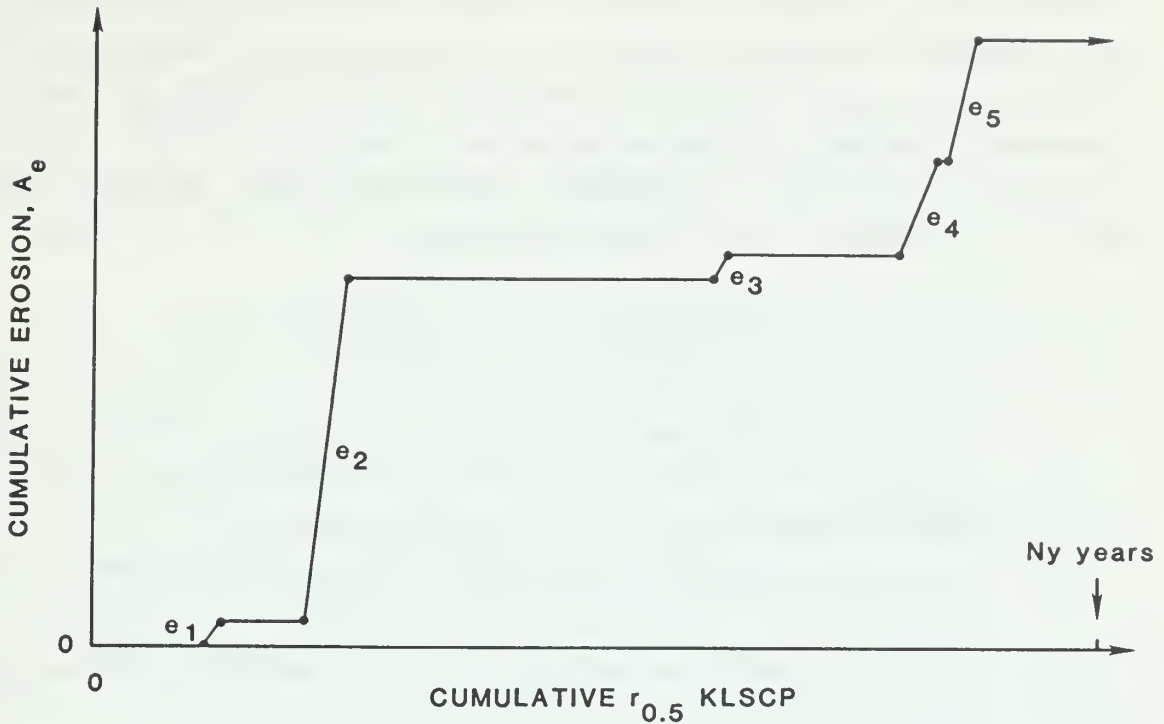


Figure 4. A graphical portrayal of the progress of erosion for a hypothetical rare runoff landscape. The term "e" represents a runoff-erosion event. While the y-axis is shown as erosion, A, it might alternately show A/LSCP with $r_{0.5}$ in the x-axis, so that the slope of any point pivoting on the origin would represent the soil factor K. The statistical stability of such estimates would be established when successive events did not greatly perturb such a calculation., No absolute time scale or perspective is given here. Also, no similar real-data plots are known.

$r_a = 0.5$. When $r_a < r_{0.5}$, calculated erosion would not be accompanied by actual erosion when $r_{0.5} < r_e < r_a$.

Additional sources of error causing overprediction could be generated by the use of K factors calibrated on humid conditions, with more frequent and more robust runoff. Locally calibrated K values on less frequent and lower runoff values might well be smaller, leading to more modest predictions.

The event calibration problem is more a matter of r_a and the nature of $h()$. Solution for USLE parameters is truly valid only at the intersection of the two functions. As shown on Figure 3, this is called r_* . Design of such trials should then be based on some analysis of these matters. Reducing an example to the absurd, an applied event r_e of less than r_a would yield information but no practical data.

From this approach, four cases can be postulated:

1. $r_e < r_a$. No runoff and no erosion. No practical data.
2. $r_a < r_e < r_*$. Runoff and erosion, but USLE parameters will be underestimated.
3. $r_e = r_*$. Runoff and erosion; USLE parameters correctly estimated.
4. $r_* < r_e$. Runoff and erosion; USLE parameters will be over-estimated.

Event calibrations should then be targeted on a more realistic value of r_* (when parameter determination is based on the traditional expression of USLE). To determine r_* , however, a more reliable understanding of the site runoff and erosion will be necessary. As a more defensible alternate, event calibrations should be done on an event model, thus negating a need for r_* .

SUMMARY AND DISCUSSION

Overview. Most of the difficulties found in using USLE on rangelands may be seen as the expected consequence of extending an empirical method beyond its base condition. The hydrologic considerations are seen as especially pivotal. Specifically, the thresholds of runoff, their relative frequencies, the scale of events and the antecedent conditions which led to comfortable application of the USLE as in agricultural watersheds lead to variant results in many wildlands.

Attempts to miniaturize USLE for calibration with synthetic events on rangelands further contrasts intrinsic differences between conditions built

into USLE and those found in the rangeland environment. Furthermore, parallels in methodology hint the inappropriateness of such endeavors. For example, the extrapolation of an event runoff equation (the CN method) to an annual expression by a simple scaling assumption would be vulnerable to severe criticism, especially if the coefficients were transformed directly and calibration was on a few synthetic events.

Thus, to understand USLE in the hydrology-crucial situation of rangelands, the hydrology role should be considered at the event level. Items should include

1. The energy-runoff threshold relationships and their distributions
2. The relative frequency of overland runoff events
3. USLE parameter performance on wildlands
4. Event runoff generation and sediment pickup

Suggestions for New Directions

The problems, opportunities, and anticipated future use of USLE on rangelands suggest a number of operational, development, and research directions that might be undertaken to enhance its utility.

1. The annual "R" factor should be defined in terms of threshold runoff characteristics rather than the customary 0.5 inch level. An approach for doing so is outlined herein. The distribution and characteristics of r_a thus need delineation. The influence of such adjustments on the defined "K" factor should also be determined.
2. The occult influence of antecedent moisture on runoff hydrology and erosion should be accounted, and incorporated into USLE parameter transferral.
3. Error or confidence descriptions for USLE performance are needed for both annual and event erosion. A beginning might be made by dealing with the error of the associated runoff.
4. Since land erosion is a composite of individual event erosions triggered by runoff, some attention should be directed to the

characteristics of event and long term runoff from land types of interest. The rich heritage of thousands of plot-years of USLE data might be a point of beginning, centering on annual and event flows, and event rain and energy thresholds.

5. Synthetic event calibration should be targeted on the r_* energy level as described. Since the definition of r_* will be difficult, this suggestion can only be seen as an ideal, hanging on a more adequate understanding of event erosion response. However, clearly obvious cases of underprediction and overprediction might be avoided by perceptive study of the site and expected responses.
6. Long term erosion plots should be established on rare-event landscapes, acknowledging the time commitment involved. Some solace for this expense might be salvaged from the realization that the installations would not need servicing at frequent intervals. Similarly, the statistics of sampling erosion for rare events deserves study, with an eye towards the stability of parameter estimates.
7. The de facto relationships between the USLE site factors (KCP) and the Curve Number (CN) might be developed. (The LS factor is related to time of concentration). This may well suggest new unappreciated relationships, highlight inconsistencies, raise new technical issues, and provide cross reference in both directions.
8. The necessary role of runoff in erosion points towards the use of the Modified Universal Soil Loss Equation (MUSLE) type equations for field situations. Thus work on such formulations should be rewarding. Calibration on diverse watersheds and isolation of the sediment delivery component should give insights to the elementary processes involved. Availability of a reliable event model should allow parameter calibration on events.

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SYMBOLS

A	Average annual erosion as calculated by USLE
A_e	Storm event erosion
CN	Runoff Curve Number
e	interval storm rainfall energy
J_a	The integral $\int_{r_a}^{\infty} g(r_e) dr_e$. The fraction of storm event rainfall energy factors greater than r_a
i	rainfall intensity
I_a	Initial abstraction. Rainfall depth necessary to initiate rainfall excess with the CN method
N_a	Mean number of storm events annually with $r_e > r_a$
N_e	Mean number of storm events annually with $r_e > 0$
N_y	Number of years
P	Storm event rainfall depth
P_a	General expression of rainfall necessary before rainfall excess
Q	Storm event runoff depth
q	Storm event peak runoff rate
r	Storm rainfall energy factor (general)
r_e	Storm event rainfall energy factor
r_a	Storm event rainfall factor based on a storm depth abstraction of P_a
$r_{0.5}$	Storm event rainfall energy factor based on a storm depth abstraction of 0.5 inch
r_*	Storm event rainfall energy factor which coincides with USLE calibration
S	Site moisture storage index used with CN method
a, b, n	Coefficients in MUSLE or modified MUSLE (Onstad-Foster) energy function
R, K, L, S, C, P	Factors in customary application of USLE. Respectively; average rainfall energy factors (R), soil erodibility index (K), length factor (L), slope factor (S), cover factor (C), and practice factor (P)

Functions:

- h() event energy response function
- g() probability density function for r
- h() probability density function for A_e
- E() expectation operator. Mean value

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